

# Double parton scattering as a source of quarkonia pairs in LHCb

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Recent results on production of  $J/\psi$  pairs in LHCb initiated discussion on double parton scattering (DPS) contribution to this process, which is not yet elaborated well. In this short report  $J/\psi\chi_c$  and  $J/\psi\Upsilon$  modes are proposed for DPS studies. Estimations for  $\Upsilon\Upsilon$  and  $J/\psi\Upsilon$  production in LHCb are presented.

Recent observation of  $J/\psi$ -meson pairs at LHCb stimulated discussion on phenomena contributing this process. On the one hand, there is leading order (LO) calculation of the  $gg \rightarrow J/\psi J/\psi$  process in the color-singlet (CS) model [1–4]. It leads to the total cross section at 7 TeV energy of 24 nb and to 4 nb in LHCb conditions. On the other hand, high flux of incoming partons at LHC energies leads to significant probability of scattering of more than one parton pairs in the same proton-proton collision [5]. Estimations of this double parton scattering (DPS) contribution to the  $J/\psi$  pairs production [6] lead to the cross section of approximately 2 nb in the LHCb acceptance [7]. Both SPS and DPS estimations are of the order of first experimental measurement in LHCb [8],  $\sigma(pp \rightarrow J/\psi J/\psi + X) = 5.6 \pm 1.1$  nb. Meanwhile, both these predictions have some uncertainties. In SPS calculations they are induced mainly by dependencies on  $\alpha_s$  and  $m_c$  parameters. DPS estimations does not account for correlations in double parton density functions and depend on a phenomenological parameter  $\sigma_{\text{eff}}$ . Thus further investigation is desirable.

In this work other di-quarkonia final states are considered in addition to the  $J/\psi J/\psi$  one. It will be shown that for  $J/\psi\chi_c$  and  $J/\psi\Upsilon$  production DPS should be main source at least at low-invariant-mass region.

Assuming factorization of two hard partonic processes  $A$  and  $B$  one can write inclusive cross section of a double parton scattering process in a hadron collision in the following form [9]:

$$\begin{aligned} \sigma_{\text{DPS}}^{AB} = & \frac{m}{2} \sum_{i,j,k,l} \int \Gamma_{ij}(x_1, x_2, \mathbf{b}_1, \mathbf{b}_2, Q_1^2, Q_2^2) \times \hat{\sigma}_{ik}^A(x_1, x'_1, Q_1^2) \hat{\sigma}_{jl}^B(x_2, x'_2, Q_2^2) \\ & \times \Gamma_{kl}(x'_1, x'_2, \mathbf{b}_1 - \mathbf{b}, \mathbf{b}_2 - \mathbf{b}, Q_1^2, Q_2^2) \times dx_1 dx_2 dx'_1 dx'_2 d^2b_1 d^2b_2 db, \end{aligned} \quad (1)$$

where  $\Gamma_{ij}(x_1, x_2; \mathbf{b}_1, \mathbf{b}_2; Q_1^2, Q_2^2)$  is double parton distribution function (PDF),  $\hat{\sigma}_{ik}^{A,B}$  — partonic cross sections of processes in question,  $\mathbf{b}$  — impact parameter and  $m = 2$  for different partonic subprocesses and 1 — for identical. It is usually assumed that longitudinal and transverse components of the PDF can be decomposed in the following way:

$$\Gamma_{ij}(x_1, x_2; \mathbf{b}_1, \mathbf{b}_2; Q_1^2, Q_2^2) = D_h^{ij}(x_1, x_2; Q_1^2, Q_2^2) f(\mathbf{b}_1) f(\mathbf{b}_2), \quad (2)$$

and longitudinal component  $D_h^{ij}(x_1, x_2; Q_1^2, Q_2^2)$  is taken as a product of two independent single parton distributions,

$$D_h^{ij}(x_1, x_2; Q_1^2, Q_2^2) = D_h^i(x_1; Q_1^2) D_h^j(x_2; Q_2^2). \quad (3)$$

This leads to a well-known simple expression for DPS cross-section in which no di-parton correlations are involved:

$$\sigma_{\text{DPS}}^{AB} = \frac{m}{2} \frac{\sigma_{\text{SPS}}^A \sigma_{\text{SPS}}^B}{\sigma_{\text{eff}}}. \quad (4)$$

CDF and D0 measurements give  $\sigma_{\text{eff}} = 14.5$  mb, which is roughly 30% of the non-single diffraction (NSD) cross section at the Tevatron ( $\approx 48$  mb). The NSD cross section at LHC is only slightly higher ( $\approx 51$  mb). This supports an assumption that  $\sigma_{\text{eff}}$  weakly depends on the total energy of interaction [10]. Nonetheless dependence on the resolution scale and consequently on the partonic process can be significant. Model of multiple interactions implemented in Pythia8 [11] MC generator tries to accounts for this dependence and predicts  $\sigma_{\text{eff}}$  for double charmonia production of 30 mb ( $\sigma_{\text{eff}} = \sigma_{\text{NSD}} / \langle f_{\text{impact}} \rangle$ ). Further we will use usual value of 14.5 mb.

LO calculations in the CS model [2] lead do the value of double prompt  $J/\psi$  production cross section in LHCb acceptance ( $2 < y < 4.5$ ) of approximately

$$\sigma_{\text{SPS}}^{pp \rightarrow J/\psi J/\psi + X} = 4 \text{ nb}. \quad (5)$$

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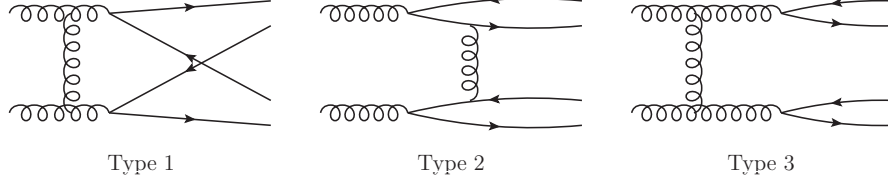


FIG. 1: Feynman diagrams for  $gg \rightarrow q\bar{q}q\bar{q}$  process.

This result depends on the  $\psi_{J/\psi}(0)$ ,  $m_c$  and  $\alpha_s$  parameters. First of them,  $\psi_{J/\psi}(0)$ , can be determined rather precisely from the leptonic width.  $m_c$  was set equal to  $m_{J/\psi}/2$ . LO running  $\alpha_s$  at the transverse mass scale was used. Taking experimentally measured cross section of single  $J/\psi$  production in LHCb of  $10\mu\text{b}$  [12] and using expression (4) one gets for the DPS contribution approximately

$$\sigma_{\text{DPS}}^{pp \rightarrow J/\psi J/\psi + X} = 2 \text{ nb.} \quad (6)$$

Sum of these contributions agrees well with the experimentally measured value [8]

$$\sigma_{\text{exp.}}^{pp \rightarrow J/\psi J/\psi + X} = 5.6 \pm 1.1 \text{ nb.} \quad (7)$$

Several methods to distinguish DPS contribution from the SPS one were proposed [5, 6]. However it would be easier to deal with process in which one of these contributions is suppressed compared to another.

Crucial feature of the CS model is presence of so-called selection rules. According to the C-parity conservation, C-parity of the final state must be the same as those of 2 initial gluons, which is C-even as they are in CS combination. That is why production of  $J/\psi\chi_c$  in SPS is expected to be suppressed. DPS cross section has no suppression in this mode and should be significant as it is known that about 50% of single  $J/\psi$  mesons originate from the feeddown from the  $\chi_c$  decays. Thus observation of  $J/\psi$ -pairs accompanied by a photon (from the  $\chi_c \rightarrow J/\psi\gamma$  decay) would be a signal of DPS contribution.

Let us consider  $\Upsilon(1S)$ -meson pair production. Calculations analogous to  $J/\psi$ -pair production in [2] lead to the total cross section at 7 TeV of 31 pb and in LHCb acceptance:

$$\sigma_{\text{SPS}}^{pp \rightarrow \Upsilon\Upsilon + X} = 8.7 \text{ pb,} \quad (8)$$

while estimation of DPS cross section based on the experimental data on single  $\Upsilon$  production at LHC [13] gives

$$\sigma_{\text{DPS}}^{pp \rightarrow \Upsilon\Upsilon + X} = 0.4 \text{ pb.} \quad (9)$$

One sees that in the  $\Upsilon(1S)\Upsilon(1S)$  mode SPS should dominate. Also feeddown from  $\Upsilon(2S)$  and  $\Upsilon(3S)$  decays should increase SPS prediction while it is already accounted for in the DPS estimation.

There are basically 3 types of Feynman diagrams for the  $gg \rightarrow q\bar{q}q\bar{q}$  process (see fig. 1). Diagrams of first type contain 1 fermion loop while diagrams of second type contain 2 fermion loops connected by an intermediate gluon. In the diagrams of second type final particles are coupled with 2 gluons and consequently these diagrams do not contribute to  $S$ -wave pairs production due to the  $C$ -parity conservation. Diagrams of the third type correspond to gluon fragmentation and contribute to CO-states production only. Thereby only diagrams of first type contribute CS  $J/\psi$  or  $\Upsilon$  pair produced. But there are no LO diagrams contributing CS  $J/\psi\Upsilon$  combined production. This final state is however accessible through  $\chi_c\chi_b$  production followed by  $\chi_c \rightarrow J/\psi + X$  and  $\chi_b \rightarrow \Upsilon + X$  decays. Meanwhile  $\chi_c\chi_b$  production does not exhibit kinematical peak near the threshold and is not expected to be significant in the low invariant mass region. Prediction of  $J/\psi\Upsilon$  production in CO mechanism made in [4] give in LHCb acceptance

$$\sigma_{\text{SPS}}^{pp \rightarrow J/\psi\Upsilon + X} = 2 \text{ pb,} \quad (10)$$

while DPS contribution found using expression (4) gives approximately

$$\sigma_{\text{DPS}}^{pp \rightarrow J/\psi\Upsilon + X} = 75 \text{ pb.} \quad (11)$$

So in the  $J/\psi\Upsilon$  mode prediction for DPS exceeds significantly those for SPS one. It is interesting to notice that for SPS  $\sigma_{\text{SPS}}^{J/\psi\Upsilon} < \sigma_{\text{SPS}}^{\Upsilon\Upsilon} < \sigma_{\text{SPS}}^{J/\psi J/\psi}$  while for DPS  $\sigma_{\text{DPS}}^{\Upsilon\Upsilon} < \sigma_{\text{DPS}}^{J/\psi\Upsilon} < \sigma_{\text{DPS}}^{J/\psi J/\psi}$ .

Thereby cross section of  $J/\psi J/\psi$  production is saturated by both SPS and DPS contributions, while for  $\Upsilon\Upsilon$  and  $J/\psi\Upsilon$  final states only one of these regimes prevail.

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